Sand Distribution and Statistical Spatial Characteristics
on Pacific Reef Platforms

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LONG-TERM GOALS

Our long-term goal is to improve understanding of sand distribution, accumulation, temporal variability, dynamic characteristics, and response to geologic substrate factors on Pacific reef platforms within the depth zone from 20 m to the shoreline.

OBJECTIVES

The hypothesis we are testing is that sand accumulation on reef platforms is influenced by hard substrate morphology. This morphology can be best understood using a combination of remote sensing and spatial pattern detecting tools. The work consists of 6 steps including a remote sensing analysis, a spatial pattern analysis, and field work data collection and analysis.

Our top-level goal is to quantify and build a geologic model of the temporal variability and spatial distribution of carbonate sand on Pacific reefs. Although sands are mobilized by waves and currents on fringing reefs they ultimately accumulate under the influence of geologic factors governing hard substrate relief (i.e., karst bathymetry, coral community rugosity, spur and groove development, antecedent topography, etc.). These factors are products of nearshore geologic processes and they exert important controls on the sandy sea floor that work together with dynamic sediment transport processes to determine sand accumulation. We seek to define the relationship between active sand accumulation and reef geologic factors controlling substrate relief.

To do this we have implemented a nested scale analysis using image classification and field data. We identify three domains of study defined by spatial scale: 1) fine-scale classification of individual sandy substrate types in localized portions of the reef surface (1 m resolution), 2) meso-scale spatial relationships between individual sandy substrate classes and their surrounding hard substrate (4 m resolution), and 3) coarse-scale statistical distributions and relationships of all sandy substrate classes in a test area, and their correlation with geologic factors governing reef substrate.

Individual pixels and groups of pixels containing elements of particular interest are identified using an Artificial Neural Network model. By identifying all similar pixels for a class, in this case "sand", it is possible to quantify the significance of their locations and distribution. Combining these results with bathymetric LIDAR data provides the link between spatial distribution and geologic factors governing substrate relief. Statistical tests, such as 2-D Fourier Spectral Analysis, are used to analyze images and bathymetry for patterns of surficial distribution.

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14. ABSTRACT
Our long-term goal is to improve understanding of sand distribution, accumulation, temporal variability, dynamic characteristics, and response to geologic substrate factors on Pacific reef platforms within the depth zone from 20 m to the shoreline.

15. SUBJECT TERMS

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After images and bathymetry are classified, combined, and analyzed, field sites representing all 3 spatial domains are selected. The objective of all modes of study is the construction of a geologic model defining relationships among and between sand accumulations and substrate geology. The model will emphasize depth, sand thickness, rugosity and relief, oceanographic factors, and geologic controls on substrate characteristics (i.e. karstification, channelization, carbonate accretion, antecedent topography, and hydrologic response).

APPROACH

Step 1 – Sand Classification

Methods are focused on developing simple and accurate techniques for sand identification in aerial photographs and digital images. Aerial photographs and digital images, those simple images with red, green, and blue components, are the chosen media because they are more common, cheaper, and require less specialized acquisition equipment than multi-spectral or hyper-spectral images. Aerial photographs and digital images additionally are the only resource available for historical sand variability analysis (an important component of this research). Using georectification a *base image* is constructed on RGB data (Figure 1).

Figure 1 Waikiki Base Map. This is a color image of the study area in Waikiki, Oahu, Hawaii. Light colored regions are sand units on the sea floor.

Red, green, and blue bands all have different water penetration characteristics, with the red band penetrating only a short distance through the water column even in optically ideal conditions. To increase the spectral depth of the data we conduct a Principal Component Analysis (PCA) of blue and green bands to provide two new channels, or eigenchannels, of information. Using the second eigenchannel provides increased distinction of bottom types, though not sufficient to accurately classify the image. Blue, green, and the second eigenchannel are used as inputs into an Artificial Neural Network (ANN) that assigns each pixel to an information class. ANN's are effective and efficient tools for rapid segregation of basic substrate information classes that in this case we reduce to two ("sandy substrate class" and "other than sandy substrate class"), thereby focusing our query on sandy substrate. The result of ANN classification is a two-information class data set, with the primary information class identifying sandy substrate.

Step 2 – Transient Sands
The second step is to begin analyzing classified results against historical images of the reef surface that have been co-registered to the base image. This visual interpretation begins to identify the temporal variability of sandy substrate, and allows for a new class, "transient sands", to be identified (Figure 2).

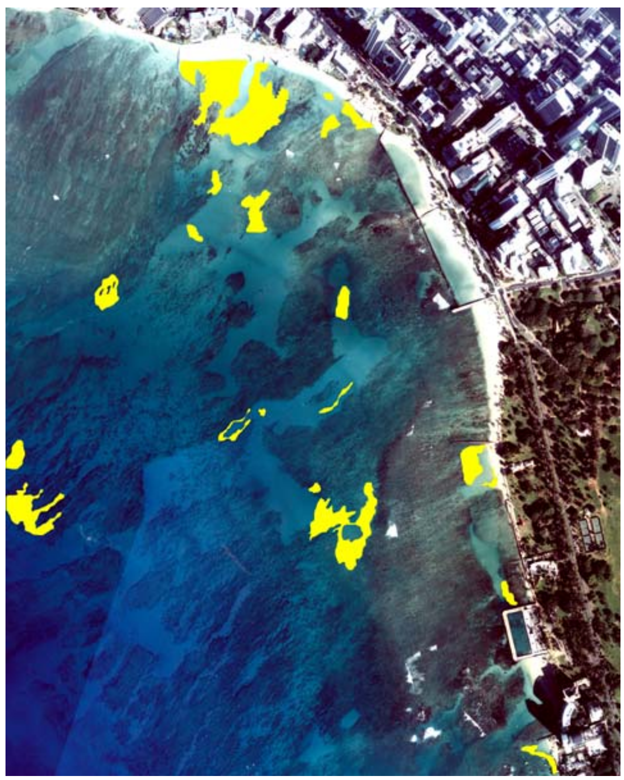

Figure 2 Map of Transient Sands. Color, digitized image of the study area. Yellow regions are visually identified as "transient sands" by comparing the base image to historical images. "Transient sands" are spread throughout the study area.

Step 3 – LIDAR Bathymetry
LIDAR (USACE SHOALS, *ca* 1999) datasets of the study site are interpolated into a sea-floor surface and co-registered to the base image. Attention must be paid to the cell size and interpolation technique, as the non-uniform point distribution of LIDAR may create invalid or unusable interpolated results. A

useful derivative of the interpolated surface is a slope analysis, displayed in gray-scale that provides detailed information on relief and slope variability (Figure 3).

Figure 3 Slope Analysis. Low intensity, or dark regions, indicate high slope angles, and high intensity, or bright regions indicate low angles.

Step 4 – Spectral Analysis

A 2-D Fourier Spectral Analysis of test areas is applied to the base image, the classified image, and the slope analysis image. This step focuses on our three spatial domains (fine-scale, meso-scale, and coarse-scale). 2-D Fourier Spectral Analysis produces directional and frequency components of each domain by examining changes of intensity within the image. The intensity changes reflect variations in different properties for each of the images (color intensity changes for base image, classes for classified image, and slope variation in slope analysis image).

Step 5 – Field Data on Sand Thickness

The multi-scale analysis described above will provide data on sand distribution, sand variability, shelf surface variability, slope, and topographic patterns at three spatial scales. Once sandy substrate domains are identified, their physical characteristics need to be measured and analyzed. Possible domain sites are located in the field, and substrate thicknesses and basic characteristics are measured. Thicknesses are measured using a water-jet probe that passes through the sand to larger rubble or hard substrate. Basic grain size determinations can be inferred from water-jet probing, and finer details will be provided from grain size analysis of a few key locations in each area. Thickness measurements will be interpolated to produce hard bottom contacts for the sandy substrate. These contact surfaces will be analyzed using 2-D Fourier Spectral Analysis and other spatial analysis tools.

Step 6 – Geologic Model
Finally, combining sand classes from image analysis with interpolated and analyzed LIDAR data, 2-D Fourier Spectral Analysis results, and field site surveys will produce a detailed description of both sandy substrate and hard substrate spatial and temporal characteristics. Small-scale results will focus on the individual sandy substrate domains, including 2-D Fourier Spectral Analysis, depth, sand thickness, rugosity and relief. Medium-scale results will focus on the statistical relationship of the sandy substrate domain to its surrounding hard substrate. Large-scale results will focus on the entire study area, relating sandy substrate domains to oceanographic factors and geologic controls on substrate characteristics. Other data sets for possible correlation include wave regime data and current environment parameters.

As stated earlier, our research seeks to test the hypothesis that sand accumulation on carbonate shelves is influenced by hard substrate morphology. The steps outlined above provide necessary information for the construction of a geological model defining hard and soft substrate interaction on three spatial scales on fringing reefs.

Chris Conger, a master's candidate for Coastal Geology in the Department of Geology and Geophysics at the University of Hawaii, is the primary analyst. Chip Fletcher, professor of Geology in the Department of Geology and Geophysics at the University of Hawaii, is the principal investigator.

WORK COMPLETED

Initial imagery and LIDAR data have been acquired for the Waikiki test site. Base image data have been transformed through PCA and a second eignenchannel created. Three bands (green, blue, and the second eigenchannel), passed through a trained ANN, and are used to construct a classified image was the result. Historical images have been co-registered to the base image, and transient sand regions have been identified. LIDAR have been co-registered to the base image and interpolated, creating a sea floor surface. Slope analysis of this surface has produced a gray-scale slope image. 2-D Fourier Spectral Analysis has been performed on the initial image, the classified image, and the slope analysis image. Work is beginning on Step 5 for our first study area.

RESULTS

Creation of an effective and efficient classification model for initial sand identification was a crucial step in the process. Identifying the second channel of the PCA as a valid input for the ANN was important for increasing the useful data depth available for analysis. Identifying the requirement to choose numerous, small, spatially well distribued training classes was essential for creating an accurate and precise ANN supervised classification model.

A manuscript describing this work has been submitted to **Journal of Coastal Research** for publication. An abstract for the work completed on the Waikiki Test Area has been accepted for presentation at the **Geological Society of America Annual Meeting** in 2003.

Recognizing that the slope analysis image was a usable data set for the 2-D Fourier Spectral Analysis was an important factor in correlating sea-floor surface characteristics and sandy substrate distribution characteristics.

IMPACT/APPLICATIONS

This research will improve prediction of the location and interrelationship of sandy and hard substrate on carbonate shelves.

RELATED PROJECTS

We are collaborating on bottom characterization with the ONR funded mine burial study.

PUBLICATIONS

Conger, C.L., Fletcher, C.H., Barbee, M, 2003. Artificial Neural Network Classification of Sand in all Visible Submarine and Subaerial Regions of a Digital Image. Journal of Coastal Research, Submitted.

Conger, C.L., Fletcher, C.H., Barbee, M., 2003. Marine Carbonate Sand Location and Substrate Morphology Analysis Using PCA and Neural Networks on RGB Images. GSA Annual Meeting.